THE SIGNIFICANCE OF SOME PHYSIOGRAPHICAL CHARACTERISTICS OF WESTERN AUSTRALIA.

By

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With a Map, Plate VI.

In travelling through the Central and Eastern Goldfields regions of this State, a geological observer cannot fail to become impressed with the constant recurrence throughout them of a quite limited number of physiographical types of land-sculpture, which are repeated over huge areas in endless variations of size and shape, but with constant and remarkable identity of the essential similarities which constitute a type. It is obvious from this identity that like causes have been operating in like manner over very widespread regions to produce like effects, and it follows from this that a proper interpretation of the physiographical evidence is likely to give important results in explaining the more recent geological history of the State. Until lately, the subject of the physiography of Western Australia had been dealt with only very briefly by writers on its geology, and usually only casually in connection with descriptions of particular localities, without any attempt, as a rule, to put forward any general account of the geomorphology of the State as a whole. In 1914, however, this absence of systematic description was greatly remedied by the publication of Geological Survey Bulletin No. 61, which the author, Mr. J. T. Jutson, very modestly calls "An Outline of the Physiographical Geology (Physiography) of Western Australia," but which well merits a more ambitious title which would be suggestive of the wealth of information therein contained. In his Part V, Chapter 1, he gives a synopsis of the opinions of previous writers on the origin and age of what he terms the Great Plateau of Western Australia, and in Part I. (p. 20), he records his own view of the matter as follows:—

"As regards the origin of the Great Plateau, the areas of exterior drainage are regarded by the writer as uplifted peneplains, but concerning that portion of the Great Plateau situated in the interior, he is somewhat uncertain whether to classify it as an uplifted peneplain, or an uplifted plain of arid erosion, but, as shown later, inclines to the idea of a vast peneplain, since uplifted to its present height." Among the opinions of previous writers cited by Mr. Jutson, it may be useful in the present connection to recall that F. T. Gregory (1861) believed "that since Tertiary time the country has been both elevated and depressed, more than once perhaps, but bodily and equably and without tilting," that E. T. Hardman (1884) states that in the ranges in the South-Western portion of the Kimberley district, "the plateau-like outline is extremely well-marked, indicating an old plain of marine denudation subsequently carved out into hills and valleys by the action of sub-aerial denudation"; that Prof. Ralph Tate (1893) pointed out that Australia in Cretaceous time was a vast archipelago, and that the antiquity of Australia as a whole is only post-Cretaceous; that Prof. J. W. Gregory (1907) held that since middle Palaeozoic times no great earth-folds have disturbed the structure of the Australian mass, and all the later movements on the continent appear to have been the vertical sinkings of wide earth blocks; that Prof. T. W. E. David in 1911 refers to the vast peneplains of Western Australia as being raised 1000 to 2000 feet above sea-level; and that Mr. Jutson himself in 1912 described the Darling plateau as a truly uplifted peneplain, and the date of the uplift as ~~post~~ pre-Pleistocene. It has been very generally recognised, therefore, that there has been much up and down movement of the State as a whole, though opinions differ a good deal as to the extent to which the movements of subsidence actually resulted in submergence of the land beneath the sea. Prof. Gregory, for example, appears to hold that the greater part of Western Australia "consists of an Archaean block or coign, which has never been below the level of the sea, although time after time the sea has washed its borders."

Since Mr. Jutson's book was issued there has been a further paper by Prof. Gregory, published in "The Geographical Journal" for June, 1914, on "The Lake System of Westralia," in which a map is given showing the country divided into a number of very flat drainage basins, gradually rising to high country over 2000 feet above the sea in the interior. His summation of the position is:—"The dry lakes of Westralia are therefore depressions in a river system which was probably Miocene in origin; these rivers have been broken up by their inability to keep their channels clear from encroaching sand dunes during the post-Miocene desiccation, which may be explained by a reduction of internal rainfall coincident with the uplift of the country for about 1000 feet." Elsewhere in the paper he refers to the suggestion of the present writer that the salt lakes might be the remains of a marine invasion, and regards it as possible, as proved by the marine limestones at Norseman, but considers it improbable owing to the varying levels of the lakes and the absence of marine fossils north of Norseman. The writer is not at all impressed with these reasons for regarding a widespread marine invasion as improbable, as the varying levels of the lakes would be a perfectly natural and obvious consequence of the gradual emergence from the sea of a submerged peneplain, and the absence of fossils is very inconclusive because, as it happens, fossils are equally absent over the country to the south of Norseman also. So far as is yet known this single locality contains all the recent marine fossil evidence available, yet while it is admitted that the presence of marine shells at a height of about 900 feet above sea levels, is proof that the land was submerged under the sea to that depth, their absence at higher levels is apparently to be held to prove that they were laid down at the limit of the submergence. The only fair deduction from the facts is that the destruction of fossil evidence of the presence of the sea has been extraordinarily complete, and we appear to have been fortunate in having the Norseman beds preserved at all to prove that there was a marine invasion.

During many journeys through the Goldfields districts the writer has become more and more impressed with the belief that there is much physiographical evidence to show that the main features of the surface relief in the goldfields areas owe their final shape principally to marine action, and that subsequent subaerial erosion has been able to do very little more than slightly modify the shape of the country as it was left by the receding waters. Also that this evidence of marine action may be found up to at least the 2000 feet level. It has been pointed out by the Government Geologist, Mr. Maitland, in his latest sketch of the geology of the State, written for the Australian visit of the British Association in 1914 (Geological Survey Bulletin No. 64), that "By far the greater portion of the State is in reality a very extensive plateau, averaging about 1,400 feet in height, though isolated portions reach altitudes approaching 4000 feet." Mr. Jutson gives a map in Bulletin 61, showing the elevations of the portion of the State south of the tropic of Capricorn, which shows a very small portion over 2000 feet in height, and a considerable area between 1500 and 2000 feet, but the great bulk of the region under 1500 feet. If, therefore the sea reached to the present 2000 feet level, all the land above water south of the tropics would be parts of the Stirling Ranges in the south, and a large island and several smaller ones in the northern part of the Murchison, East Murchison and Mt. Margaret Goldfields. It is the object of this paper to discuss the physiographical evidence and show how it sustains and corroborates the marine theory.

There is usually a very great similarity in the scenery of our Eastern and Central Goldfields. Everywhere we find great plains, often extraordinarily evenly level over large areas, with low rounded hills or groups of hills rising from them with very gentle slopes. A steep slope is rather an exception, though many such are to be found without difficulty. Rather frequently, when the rock composing the hills is a hard one capable of resisting erosion, as in the case of the well-known "jasper-bars," it stands out in rough well-marked ridges, which follow the lines of strike of the hard rock. Where the hills are composed of dense and little-jointed intrusive rocks they usually take large rounded outlines, forming distinct and often somewhat prominent hills, but those formed of the more schistose and jointed rocks commonly show less relief and much less curved contours. The hills formed by granite are of very distinctive appearance, being usually bare, bald surfaces of hard rock, protruding from the surrounding plains. These bare surfaces are commonly more or less pitted with shallow small solution basins in which water collects during rains. The granite protuberances very often strongly remind one of rocks and islands standing up out of a sea, and along the south coast east of Albany, we may see exactly the same type of protruding granite rocks in the numerous islands which there are seen standing quite similarly out of the actual sea. The similarity of scenic type is so exact as strongly to suggest identity of the sculpturing agencies.

Where the rising ground occupies a considerable area it frequently happens that smaller plains are found on the hills at various levels, so that an observer, in passing through a hilly region, frequently travels most of the way over very flat surfaces, with little elevated country in sight, although on the whole the surface is a good deal higher than the surrounding main plains, and from a distance appears to form a distinct "range." The "Black Range" for example on being approached from the west side is seen for many miles away as a distinct high ridge, but plain after plain is crossed in getting to it without having almost any perceptible rising of the road, until one finds oneself travelling —still on flats—over the top of the high country. This characteristic of the larger masses of high land is so usual as to be fairly regardable as normal. Another good example is seen on the road from Meekatharra to Peak Hill. The Robinson Range, on which Peak Hill stands, is seen from the plains to the south of it as a high blue range, but one rises so gradually on to it, over plains wth very gentle slopes connecting them, that the top of the ridge is reached without having encountered any very perceptible acclivity. And the top when reached is itself more or less a number of small plains separated by low-lying ridges of higher ground, and with Peak Hill and another similar conical point of hard quartzitic rock standing up like pyramids from the plains. Peak Hill itself, it may be mentioned, is a very small affair, little more than a large natural cairn formed by the outcrop of a belt of hard quartzite and the *talus* therefrom. On the flat at its foot, in the open cut workings of the Peak Hill mine, the surface of the ground is seen to consist of a ferruginous conglomerate of stones and coarse gravel, many of the stones of which are well rounded, showing them to have been worn smooth by attrition in moving water. This is not at all a unique occurrence, for there is quite distinct "deep lead" ground at Nunngarra on the Black Range, which shows water worn gravels in places, and distinctly water worn boulders are visible on the "Big Patch" at Quinns, high up on Nowthanna Hill. At Quinn's also there is a distinct well-rounded brown iron ore conglomerate, apparently not concretionary, near the saddle on the road to Burnakura over the hill, which seems to be a cemented gravel and not a pisolitic deposit. Both at Peak Hill and at Quinn's, however, there is a possibility that these water rolled stones *may* belong to formerly existing basal beds of the Nullagine series, the bulk of which have been entirely removed by erosion, except for these relics, so too much reliance cannot be placed on them alone as evidence of these high plains having been recently subject to the action of moving water. The writer has noticed on many occasions nevertheless, that rounded and subrounded stones—not demonstrably waterworn as a rule however—appear to be much more common on the higher slopes of ridges standing well up out of the plains than in the latter and along the lower skirts of the hills. A good example is seen on the road from Leonora to Lawlers, a few miles south of Diorite King, where the road crosses over a hill of some height. Here rounded stones and boulders—which may however be merely weatherworn and not waterworn—are fairly common on the higher slopes of the hill, but wanting as one gets down on to the plains on each side. Mention may also be made of a very distinct bank of well rounded coarse conglomerate near Wiluna, well up on the ridge near the State Battery, which is unequivocally a coarse gravel deposit. Professor Gregory has alluded to the writer's mention of this gravel bank, but the description given by him seems to apply to a quite different locality and shows that he could not have seen the same section as was referred to. Wiluna, however, is very close to the southern edge of the Nullagine beds, and there is just a possibility that this gravel bank also may be a relic of these, though it is not very likely.

A point on which some stress must be laid is that the plains are found at all elevations up to about the level of Peak Hill (1900 feet). They usually merge one into another with a generally very gentle southerly or westerly slope forming the very flat basins to which Professor Gregory has drawn attention, gradually dipping towards the coast. The average gradient is extremely flat; for example the difference in level between Lake Way (2030 feet) and Lake Lefroy (1050 feet) is 980 feet, but they are about 320 miles apart, giving an average grade between them of only 1 in 1724. This extreme flatness of the grade of the main central drainage basin has to be borne in mind in considering how it may have been brought about, as it is not easy to get a convincing explanation of it by reference solely to subaerial erosion.

The low relative height and usually very thoroughly rounded shapes of the hills in the Central and Eastern Goldfields districts indicate a very advanced stage of erosion of what doubtless were once much higher and more important hills. Very little more and the hills would be cut down entirely to one great peneplain. This form of level surface characteristically results from long-continued sub-aerial erosion, and its occurrence is therefore to some extent *prima facie* evidence that the land has been for a very long time subjected to the subaerial agencies which would bring about such features. It may fairly be submitted, however, that if a land surface in such or approaching such a mature stage of planation were to subside below sea-level to such an extent as to bring the sea over the greater part of it, and were again to be elevated well above the sea level, the effects of the original merely subaerial planation would be greatly accentuated by marine erosion during the periods in which the surface was in process of being submerged and raised again.

While the low hummocky type of hills surrounded by plains is characteristic of the lower ground, there is a very marked change in the type of land sculpture when we get into some of the higher country. One of the best examples is seen in the Frazer Range to the west of Peak Hill. Here we suddenly find ourselves in the presence of a hill-sculpture of a type quite unlike the hills previously described. Instead of low rounded hills there are rough ragged peaks with their sides deeply furrowed into hard sharp-edged outstanding ridges and deep rough ravines, and giving jagged pointed outlines from all aspects. The type is that of an outstanding rock-mass deeply dissected by storm-water erosion. But at the foot of it, at the Mount Fraser mine, the approach is over wonderfully level plains running against the hills exactly as one sees sea-beaches form against a rugged hilly shore. A short distance out on the plain a well has been sunk to a depth of about 140 feet, passing through alluvial material containing much small gravel, fairly rounded, of river type, showing that the flat has a buried valley in it. The existing flat carries one of the numerous branches of the Murchison River, seen as a running stream only after heavy rains. Between the well and the Mount Fraser mine the track passes over one of the most striking geological curiosities it has been the writer's fortune to observe. The bedrock is a hard prismatically jointed greenstone, the surface of which is often quite bare of soil for yards at a time. In one or two places noticed, the bare rock surface was seen to be cut to a quite even plane, forming a smooth floor to which the joints gave the appearance of a mosaic pavement, the prismatic columns being there rarely as much as an inch across. It is difficult to believe that wind could have planed such a hard rock to an even surface, though the occurrence is quite comprehensible if regarded as formed by beach erosion. At this place also the resemblance of the edge of the plain to a beach is most marked; it is quite level and runs in and out among the rocky spurs meeting it in the most regular manner at one level, forming inlets, bays, and every feature seen on a beach. It must be said, however, that no beach gravels were seen at this point.

At the Horseshoe some 17 miles northward from Peak Hill there are extensive deposits of gravel, not nearly so thoroughly waterworn as is usual on a sea beach, however, along the foot of the Horseshoe mountain, which are well seen where they have been worked for alluvial gold. These gravels maintain approximately the same level for some distance along the flank of the range, and lie at a much steeper angle of slope than is maintained into the plain alongside, which soon becomes practically level. They appear to be a talus from the slopes of the hill, roughly sorted along a horizontal line by the action of water, but not subjected to very violent or long continued abrasion. All the way from Peak Hill to the Horseshoe, the beach-like contact of the plains with the hills is very well-marked. At the "Breakaways," about 12 miles from Peak Hill, the road leaves the plain over which it has been travelling and turns as if about to run up on the higher ground apparently, but is soon found to continue on a strip of the plain running between an island of higher ground and the mainland. The higher ground is cut to steep escarpments ("breakaways"), which usually have but little talus at the foot of them, and curve off at the foot of the cliffs in quite characteristically beach fashion. The level of the plain is perfectly preserved all round the foot of the cliffs, very sinuous though its outline is, and round the islands. The conclusion seemed quite irresistible that here we had a beach cut by a body of water occupying what is now the plain.

Reverting, however, to the hills at Mt. Fraser above the beach line, it is to be noted that we no longer get the hummocky rounded outlines so usual in the hills at lower levels, but a quite distinct type, that resulting from well advanced erosion still in the most active stage. The Horseshoe Range and the high peaky country towards Mt. Egerton show the same type persisting in the highest ground, with the lower hills, as at the Mt. Egerton goldfield, worn down to flattened stumps which may very possibly owe their final shape to having been completely submerged. The Nullagine beds are here again, however, visible in the near vicinity, and it is quite possible that the erosion which cut down the old rocks to such flattened stumps was pre-Nullagine in point of time, and that they been merely uncovered again by subsequent erosive action.*

The same very sharp contrast between the types of sculpture of the hills in the lower and higher country is seen very markedly in the Pilbara goldfield. The high mountainous country between

* A later visit to the Upper Gascoyne District has led me to think that the rocks at Mt. Egerton, taken to be pre-Nullagine, may belong to the Nullagine series.—A. M.

Marble Bar and Lalla Rookh stands out like a rugged island from the smoothly-worn plains surrounding it, and the edges of the plains lying against the high land all round maintain a strong general likeness to beaches. The hills themselves are peaked, furrowed, and jagged, the peaks often being capped with nearly horizontal strata of the Nullagine beds, showing the mass to be a deeply dissected old plateau. The Wodgina range also stands out from the plains as a similar rough high hill, deeply furrowed. The high rough range at Warrawoona presents quite a similar contrast to the plain country on each side of it, the latter being in the last stages of peneplanation, while in the ridges storm-water erosion is still very active.

In the south of the State, the Stirling and Eyre Ranges show the same feature, rising in rugged rocky peaks from surrounding country in an advanced stage of planation, quite similarly as the rocky islets on the south coast rise out of the surrounding sea. It is clear that there must be some physiographieal explanation of the marked difference in the character of the rugged peaks as compared with the well-rounded hummocky country and plains round about them. Petrological differences have no doubt had a great deal to do with the question, the outstanding island-like heights of Wodgina, Lalla Rookh, and Warrawoona being mostly composed of very old metamorphic and igneous schistose rocks, while the surrounding plains are mostly granite, and the Stirling and Eyre Ranges are likewise composed of old sedimentary rocks surrounded by granite. In both the Pilbara and Stirling regions however, the rocks which form the high hills are themselves often cut down round the skirts of these hills quite equally with the granite, and are thus found extending some distance into the surrounding plains, as is also the case at the Robinson Range. It would seem most probable therefore that though these high lands stand out principally through their resistance to weathering in the first instance being greater than that of the granites round them, they have suffered erosion round their bases to the same approximate level as the granite round about them owing to the action of an erosive force acting on both without discrimination. The only such force competent to produce the effect as we now find it seems to the writer to be marine erosion, and it is therefore believed that these island-like hills were really islands with the waves acting round them to reduce the lower country to one approximate level.

The topography of the country crossed over in travelling from Port Hedland to Marble Bar is very instructive. After crossing a small strip of superficial limestone right at the coast, the road runs almost level for miles over sandy plains, which gradually are found to have a coating of soil—usually very shallow—upon a planed-down surface of granite bed-rock. After a time occasional low ridges of granite and small hills of granite are encountered, but the plain is seen to run round these and to go on inland continuously. It is slowly rising all the time, but at a grade imperceptible in travelling. In 89 miles from Port Hedland to Coongan, the rise is 406 feet, or an average grade of only 1 in 1157, or 4½ feet per mile. As we go inland the isolated ridges and small peaks of granite become larger and more common, but the plain runs continuously round them as before, until it strikes against the sides of the main island-like mass of hills lying between Marble Bar and Lalla Rookh. Many of the more prominent granite hills rise quite steeply from the plain, often with a talus of large rocks at their base, exactly resembling granite islands off the coast. From a high hill the general appearance of the plain being a sea and the hills islands rising from it is most striking. The plain sweeps away to the north of the main island, well to the east of the Coongan River, and through the Doolena Gorge an easy way opens into the hills and enables us to reach Marble Bar (railway level 603 feet). To the south of the island the plain sweeps round continuously, broken by projecting ridges running out from the main mass of hills, by separate islands like the Wodgina Range, and by high black doleritic ridges, to Corunna Downs, and well on towards Nullagine. Here it must be fully 700 feet above sea level, probably more, but it is practically continuous right from the sea beach up to this level. For the most part the bed rock appears to be quite close to the surface, though doubtless there are many places where the superficial material is of considerable depth—usually, however, much less than 100 feet, as is shown by the numerous wells—and we therefore see that the whole of this huge peneplain may be taken as cut fairly evenly from the solid granite rock. It is very noticeable also that where the rock is bare at surface, and in the outstanding islands and ridges, the granite generally is very little weathered, but on the contrary is fresh and hard. In this it resembles the wave-swept granites on the coast, and numerous granite bosses on the eastern goldfields, but this condition is difficult to reconcile with any theory of purely subaerial erosion, whether by rain and river action, or by wind erosion—both of which require softening of the rock by weathering before there is much perceptible removal of material. The features are exactly those which would result if the country were to subside gradually until the sea reached the vicinity of Nullagine, and then rose again to its present level. The plain is practically continuous from the foot of the high land inland to well out to sea from the coast, the sea bottom continuing to shelve seawards in continuation of the plain. At Nicoll Bay near Roebourne, there is an inland extension of the beach which is said to be only very rarely covered by the sea, and which shows as a bare mud flat of great extent sloping very gently seaward. At its inland margin there are some small sandhills and then the mud flat continues inland on much the same grade. The sandhills at the head of the bay, and the small marginal cliffs where the beach sets in against the higher land surrounding it towards the sea entrance, mark a stage of rest in the gradual retreat of the sea water, and are absolutely similar to like sand hills and breakaways on the margin of many of the inland lake basins.

But why, it will be asked, should we appeal to marine planation, when the peneplain might possibly be explainable as due to ordinary fluviatile planation. There are several considerable rivers traversing the plain, e.g., the Shaw, the Coongan, the De Grey, the Turner, the Sherlock, and the Yule. These all flow down across the plain, and at times after heavy rains they carry large flows of water, and become wide powerful rivers, of great erosive capacity. Such rivers are well-known to be potent agents in reducing the lower parts of their valleys to wide flood-plains, through which they meander with frequently changing courses, here cutting down into the bedrock, and there levelling up hollows by filling them with sediments. No doubt there is a certain amount of this action in the case of the rivers referred to, but in going through the district it did not appear to the writer that there was much evidence of its having been either extensive or long continued, certainly not to the extent of being the main agency in reducing the country to its present state of even planation. On the contrary most of the rivers appeared to be cutting down their beds, having generally fairly straight courses without meanders, and high banks on each side of wide beds capable of carrying the floods without overflowing on to the plains. Where the Shaw River was crossed near the "Gorge" there seemed some appearance that the bed of the river was excavated out of alluvial material altogether, giving some support to the flood-plain theory, but this might be equally well explained on the marine planation theory by supposing that the Shaw River debouching out of the mountainous country on to the edge of the shallow sea would form a considerable "fan" or "delta" of gravel, through which it would cut its way downwards as elevation of the land led later on to retirement of the coast-line. So far as the writer's observation of these rivers has extended, it would appear to be an allowable generalisation to make that they are all, from Pilbara southwards to the Murchison, engaged in cutting their beds more deeply into the plains which they traverse, and not in building flood plains. Confining the instances to such as have been personally visited, this would apply to the rivers just now mentioned, and to the Jones River, the Harding River at Roebourne, the upper feeders of the Ashburton and Gascoyne Rivers crossed on the route from Peak Hill to Nullagine, the branch of the Gascoyne River seen between Peak Hill and Mt. Egerton, and the upper feeders of the Murchison River, seen on the south side of the Robinson Range. Further south, in the goldfields districts, the streams are not usually traceable for great distance as recognisable watercourses, but at Poison Creek and Jones's Creek on the Leonora to Lawlers road, there are other good examples of streams cutting down into their beds rather than flooding and building up plains. Where the Lawlers road crosses Poison Creek, there is a distinct appearance of stratification in the ferruginous grits seen in the sides of the creek bed, and something of the sort has also been noticed in the bed of the Gascoyne (S. Branch), near Mt. Egerton, and in that of the river on the track from Ruby Well to Wiluna. At this stage, however, we may leave the question of the formation of the superficial material composing the plains to be taken up later on when some other evidence bearing upon it has been described and examined. The point of most importance just at present is that the existing rivers are cutting down into the plains and not building them up. Nevertheless, it is not over-looked or forgotten that comparatively slight movements of elevation and subsidence of the land as a whole may alter the grade of rivers from time to time, so that at one time they tend to fill their valleys with alluvial flood-plains and at another to cut down through these deposits on to the bed-rock again. It is therefore freely conceded that by itself no great significance should be attached to the fact that the existing rivers are cutting into the plains which they traverse, nor can their present phase of action be taken to prove that they have not themselves formed these plains in the first instance. It is when taken in connection with a number of other considerations that their evidence should be regarded as corroborating the marine planation theory rather than that of river erosion

Before leaving the subject of the existing rivers, however, mention should be made of a feature of several of them which may be of much significance in assisting us to trace the historical development of the present topography, namely, the numerous "gaps" which are so noticeable in the N.W. districts. Many of these are described in chapters 1 and 2 of part VI. of Mr. Jutson's bulletin, previously referred to, closely resembling one another in the general feature that rivers are found breaking through ranges of hills quite unexpectedly, without any very visible reason why they should have been able to find an outlet through the high country instead of going round it, following the present low ground. If the country on the up-river side of the hills were generally high, we might understand that it has been formerly higher than the hilly country traversed, and that the rivers have cut their way down through the hills simultaneously with a general lowering of the upper parts of their basins to a level much below that at which the hills were originally attacked. But the most curious point about the gaps which the writer has seen, is that they leave a plain on one side of a ridge of hills, plunge through the ridge, and come out on another plain on the other side, and that if the ridge is followed along its length the plain on the up-river side is found to be practically continuous with that on the down-river side, round the ends of the ridges. The Shaw River has three "gaps" of this sort, two where it runs across a pair of high hard ridges of gabbro, and a very long one where it goes right through the heart of the high hilly country lying between Marble Bar and Lalla Rookh. Again, close to Marble Bar the Coongan River is found cutting its way through the hills quite similarly, emerging on the plain country through the picturesque Doolena Gorge as a wide flat-bedded channel walled by precipitous rocky sides. It is difficult to find a consistent theory of the erosion of these gaps and gorges, occurring as they do on what would appear to be naturally the lines of greatest rather than of least resistance, and of the prevalence of such gaps as a recurring characteristic in many different streams, by reference to sub-aerial erosion alone, but a good deal of the difficulty disappears if we regard the surrounding plains as having been occupied by the sea, and the hills and ridges as islands standing out of it. Doubtless the higher land would be cut deeply into by valleys formed by storm-erosion before the subsidence took place which converted them into islands, but once they were submerged to any considerable extent, so as to allow the sea to convert the higher peaks into groups of islets, the breaching action of the water, aided by currents round and between the islands, would be quite competent to account for much cutting down of channels between islands. As the succeeding elevatory movement progressed and the islands arose more and more out of the sea, it seems probable that some of the main channels cut by the water between islands would tend to be cut deeper as being the most direct outlets to large areas of water, partly imprisoned on the inland side of the ridges, and that these flows would determine the form of the basins left when the sea had entirely retreated. The stormwater outfall would naturally follow the course shaped by the retiring sea waters.

A very beautiful example of a gap in which there is no river, is seen on the road from Peak Hill to Nullagine, about 25 to 30 miles out from Peak Hill. For this distance the track lies over very level plains, cut into here and there by a "creek," which is one of the heads of the south branch of the Gascoyne River, and the shallow sections exposed in the watercourses show the soil to be underlaid by layers of ferruginous compacted sand and small pebbles. In one place numerous thin flakes of hard whitish limestone were picked up, showing the presence of beds of the Nullagine series. Several clay pans were seen, in which fresh water would accumulate during rains. While passing over these plains the road is heading towards a blue range of hills, visible for many miles, and as one gets closer and closer to this range, it seems impossible that it can be crossed except by climbing over it. But suddenly a wide pass opens right through it, and the plain continues as a flat wide strip of level ground, plentifully covered on surface by subangular stones, between steep slopes on either side. Soon the road emerges again from the range on its north side, and continues for miles over more plains without having risen at all perceptibly to the eye in crossing the range. Doubtless exact measurements would show a good deal of variation in level, as the range appears to be a watershed between two drainage basins. Further north the plain runs along the foot of several hills, here mostly formed from the Nullagine beds, and everywhere the contact between the plain and the toes of the hills preserves its beach-like characteristics. There seemed to the writer to be no possible explanation of the extraordinary uniformity of level of the plain, and unbroken persistence of the beach type of the edges of it, other than that it took its final shape from being covered by a sheet of water. It did not seem possible to reconcile such extreme regularity of planation with any known action of wind, or wind and rain combined, as erosive agents. There must be a small rise and fall in the plain country, however, for the road over it, though showing no grades very perceptible in travelling, gradually passes from the watershed of the Gascoyne River on to that of the Ashburton. The stock route wells along this track are mostly sunk, apparently in deep soil, with sands and clayey little coherent strata beneath, of probably quite recent age, but some of them seem to go into the Nullagine beds.

At the Ilgarere copper field we find great stretches of plain country, sparsely covered with "mulga," and often quite bare over considerable areas. These plains resemble those usual further south in the Eastern Goldfields, in being mostly covered on surface with a plentiful sprinkling of iron oxide and cherty gravel usually somewhat rounded, but possibly owing the rounded shapes more to concretionary growth in the case of the ironstone gravel and surface wear and weathering in that of the other stones than to water attrition. This feature will be considered later on. On the west side of one of these plains we come to some hilly country, composed of slates and basalt of the Nullagine series, and fairly deeply cut into by a number of distinct "gullies," evidently eroded by running water within the most recent times. One branch gully came up into the plain and could be seen to be partly cut out of it and to lie below its level. These watercourses were parts of the headwaters of the Ashburton River, and in them ordinary river erosion is evidently proceeding rapidly now whenever storms supply the necessary water to cause the streams to fill. The watercourses are evidently younger than the plains, and cutting back into them. This shows that the formation of the plains must date back some considerable distance in point of time, and that there has been a change of conditions which has allowed of the starting of a cycle of river erosion, still in quite an early stage.

PLAINS—"BREAKAWAYS"—AND SALT LAKES.

In the East Murchison and Mt. Margaret Goldfields and southwards from them to the south coast, we find ourselves in a region of small rainfall in which running streams are rare, and cases of appreciable river erosion almost entirely absent until the coastal strip is reached. The most prominent physiographical characteristic of this part of the country is extreme peneplanation, there being no really high hills, such as there are being of the worn-down hummocky type, and the greatest part of the area is occupied by extensive plains and salt lakes. As previously mentioned the plains generally merge into one another—though often we have the main parts of each at considerably different levels—and dip on the whole very gently southward. One of the best examples of this sort of country may be seen between Meekatharra and Cue. There are two principal lakes in this region, Lake Annean and Lake Austin, with several smaller ones like the lake near Quinn's. The lakes occupy the lowest parts of very flat basins, and have very ill-defined margins in most places, the bare mud flats along their edges becoming covered gradually with a growth of vegetation, which is scanty at first, but soon gets more luxuriant as one passes outwards from the salt-pans. But one may go on for miles out from the lakes without encountering any rise in the plain country perceptible to the eye, the grades being so flat as to be almost unnoticeable without precise levelling. From Lake Annean one may go over plains eastward, by going round the higher land at Quinn's and Burnakura, and reach Quinn's Lake, and from there go south-westerly, all over plain country, to Lake Austin. Coming south from Lake Annean one may also follow plain country all the way to Lake Austin, although the railway goes over higher ground at Tuckanarra and Stake Well. Lake Annean however, is quite 80 feet higher than Lake Austin.* The lakes are seen to be merely the lowest depressions in one large plain which has a slight dip southward. On following this plain outwards, we find that it very commonly is fringed with lines of cliffs, often 50 to 100 feet high, usually cut from weathered granite much lateritised on the surface. These cliffs (escarpments) are known on the fields as "Breakaways," probably from some idea that the ground has broken and fallen along them. They show no sign, however, of being fault-scarps, being very irregular in outline as a rule, with often outlying "stacks" separated from the mainland and having scarps all round them. The cliffs are full of small caves and rock-shelters worn out of the laterite and the soft kaolinised granite lying beneath it, and often there are fallen blocks of the laterite at the foot of the cliffs. Very usually the slope of the plain curves up very perceptibly to the toe of the cliffs, but the general horizontality of the edge of the plains along the bottom of the cliffs is very marked. The shapes and outlines presented along the contact of the plains with the cliffs are quite similar to those seen along the cliff-lined shore of a sea or lake, and after close examination of many of them with rival theories of wind and water formation in mind, the con-

*Cue Station 1485, Day Dawn Station 1398, Nannine Station 1475 Austin Station 1364, Nallan 1389, feet (Railway heights).

clusion has always seemed to the writer quite unavoidable that these scarps have been formed by the breaching action of a considerable body of water occupying the area now represented by the plains. Quite similar "Breakaways" are seen in parts of the shores of Lake Lefroy and Lake Cowan at the present time, and the scenery along almost any of these "breakaways" continually recalls that seen along any sea or lake shore which is fringed with water-worn cliffs. When we see the features characteristic of cliffs caused by sea or lake erosion, reproduced along the shores of salt lakes like Lakes Cowan and Lefroy, which are almost certainly raised up portions of an old sea inlet, extending deep inland from the south coast, and find them again further north round the plains of which other salt lakes and salt pans are the lowest depressions, the conclusion seems irresistible that the mulga-clad plain of the north is merely a somewhat later stage of the salt lake basin further south, and that the surrounding "breakaways" represent the cliffs formed when these plains were occupied by large bodies of water.

When speaking of the "breakaways" of the Murchison, East Murchison, and Mt. Margaret goldfields, which are the part of the country in which the finest examples of this feature are to be found, it is necessary to notice one very striking characteristic of many of them, which requires to be explained by any physiographical theory which attempts to account for the present relief of the country. Most of the best marked "breakaways" are flat-topped, and a little examination shows that the flat-tops are remains of an old plateau which has been very extensive. The Flat-topped Hill at Cue for example which is now an isolated "stack" or "butte" has evidently been part of the adjacent flat-topped hills nearer the town, which like it, are capped with a lateritic covering derived from the kaolinised granite forming their lower portions. At intervals all round the Cue plain this plateau is seen, especially a few miles to the east of Gabanintha on the road to Wiluna, and on the south side of the plain, where the cliffs are so prominent as to have found special mention on the maps. Other good examples are seen on the road from Cue to "The Pinnacles." The present plain appears to have been excavated to a depth of probably as much as 100 to 200 feet out of a much older plain of which only flat topped portions protected by a hard lateritic covering have survived. Quite similar cliffs with lateritic flat tops to them are seen again some miles north of Mertondale, high enough to receive special mention on the map, and others near Wilson's patch, on the high ground on the road from Lawlers to Lake Darlot before dropping down to the level of the lake plain, at Hell's Gates some eight miles east of Maninga Marley on the road from there to Lawlers, and a particularly good example at Walkinjerie, a little west of the road from Sandstone to Birrigrin. The Walkinjerie hill, as it appears from the plain, is a narrow plateau of weathered granite, lateritised on the top surface, almost perfectly flat on the top, and surrounded by plains probably quite 70 to 80 feet lower than the plateau. The cliffs or "breakaways" forming the edges of the plateau are mostly very precipitous, and not easy to ascend except in a few places. They show all the characteristics of beach cliffs particularly well. On the west edge of the plateau about 12 feet down from the top in a sort of shelf in the scarp is the Walkinjerie rock-hole, well-known to travellers on the Birrigrin road as carrying a good supply of water. The rock-hole catches the drainage from a fairly large surface of the flat top of the butte, but its occurrence where it is found, on the face of a precipice, is very unexpected and not very easy to explain.

There are several possible explanations of this older plateau. It seems most probably quite considerably older than the present plains, and it may well represent part of a peneplanated surface formed before the subsidence took place which submerged the land and allowed a shallow sea to carve the present features. It is even rather likely that this surface was to some extent a reappearance of an immensely older one, on which the beds of the Nullagine series had been deposited, for traces of these are found not very far to the north of this region, and the big mass of them in Mt. Yagahong shows that they must have been a thick and extensive series. It is obvious that before the Nullagine beds were laid down the underlying old rocks must have been planed down and submerged, and when subsequent erosion removed the covering beds again it seems possible that much of the old planated surface might be uncovered without being itself much more deeply eroded than when previously a land surface. For the purposes of the present paper it is sufficient to regard this older plateau as part of an older land surface probably antecedent to the last submergence which mainly determined the existing relief. It may represent an older marine plain, possibly dating back to the subsidence which led to the formation of the Eucla limestones.

Further south there are frequent occasional traces of an older surface in outliers of laterite and lateritic conglomerate found every here and there lying on the old rocks in such a manner as to show them to be merely relics of a much more extensive formation. One such isolated block—a small one—of ironstone conglomerate near Mt. Monger, was found to have been nearly undermined by alluvial gold diggers, the basal layer of the conglomerate containing a little gold. The lateritic beds at Coolgardie railway station and the Coolgardie Hospital are a good example of this old superficial formation. Whether the auriferous sandstones and grits of Kintore are of this age or much older, is at present quite an open question; they also are a relic of an older superficial formation, mostly obliterated during the final carving out of the existing relief.

"DEEP LEADS."

In writings on the subject of our plain country it has been somewhat usual to have a good deal of insistence placed upon the point that in them the bedrock is generally very close up to the surface so that there is only a very small depth of soil covering it. There is no doubt that such a condition is of very common occurrence, there being many places where the planed surface of the bedrock is practically bare. This is well seen in several places along the shores of Lakes Cowan and Lefroy, in the case of which it can hardly be attempted to be questioned that the levelling or planing agent has been water. Yet it is known from the few borings which have been made in these lakes, that the detrital material in one case at least, is 377 feet deep below the present surface of the lake bed, and so little has been done to test the depths of the basins that it is entirely premature to assume that they must always be shallow. It must be regarded as still quite an open question whether these lakes ought not to be regarded as filled up valleys of quite considerable depth rather than shallow eroded rock basins. There is quite a large quantity of evidence now accumulated on the subject of the "alluvial deep leads" not uncommonly found on our goldfields, which goes to show that under the plains there often are numerous valleys of considerable depth in the bedrock. Some examples may be cited:—The "Lady Mary" lead near Norseman is a buried watercourse running into the Lake Dundas basin. Where the lead was first found the ground was shallow, but as it was followed towards the lake the prospecting shafts became successively deeper, up to at least 70 or 80 feet, the grade of the old watercourse falling more steeply towards the lake than that of the present surface does. If both grades continue as at present, the valley of the old watercourse must lie well over 100 feet below the level of the present bed of Lake Dundas.

The "Princess Royal" lead is a quite similar buried watercourse, running under the residence areas at Princess Royal and out towards Lake Cowan. The shafts down to the auriferous "wash" were shallow at the southern end, but the lead became deeper and deeper as it went towards the lake, and the last shafts were about 90 feet deep. It was in the workings from one of these shafts that the sponge spicule deposits described by Dr. Hinde were discovered, which he has taken to be of deep sea origin. The bottom of this lead below Lake Cowan is probably quite 100 feet below the present bottom of the lake.

At Kalgoorlie there are several well-marked "deep leads" formed by a system of buried watercourses running from the Maritana Hill westerly and southerly under the flats on which are the towns of Kalgoorlie and Boulder. Near the hills the "leads" are shallow, but they attain depths of 90 to 100 feet below the flats. The surface slopes very gradually and gently to Hannan's Lake, but the grade of these older watercourses, where they were worked, is considerably steeper than that of the surface, and if it continues they must lie well over 100 feet below the present bed of the lake. Their course however, has not been traced down to the lake, and the bedrock appears to be close to surface wherever holes have been sunk in the edge of the latter. It does not follow, if the lake beds are filled up old valleys, that the present lakes must necessarily be over the deepest parts of these old valleys, and it is quite possible that the latter may lie under other portions of the flats surrounding the lakes.

Another quite similar deep lead has been traced from the east side of the Boulder Hill at Trafalgar, down into ground up to 118 feet deep in the flat east of the hill.

At Bulong the "Oversight" lead is traced by shafts from shallow ground, 10 to 15 feet deep, down under the flats surrounding Lake Yindarlgooda, the deepest shafts being there somewhere about 140 feet deep. Here the "lead" opened out into a wide flat-lying layer of gravel, too poor in gold to be worth following. The bottom of the "lead" is well below the present level of the lake, and the grade of the old watercourse is much steeper than the slope of the present surface towards the lake. As at Hannan's Lake, the bedrock at the present lake is said to be visible practically at surface, so the deep ground—if not cut off by faulting—must lie under some of the surrounding flats.

At Kanowna the "deep leads" have been very famous for their large yield of gold. They form a whole series of buried watercourses, Wilson's Gully, the Cemetery Lead, the White Lead, the Fitzroy lead, and the Q.E.D. lead all uniting to form the North lead. At its deepest known point the lead is well over 100 feet below the present surface. On the eastern side of the hill on which is the Robinson mine, there is yet another well-marked lead, the "Moonlight Lead," of which another branch was discovered not long ago. This runs down to about 80 feet below the surface at the point where further sinking on it was abandoned. These leads lie under flats which join to the northwards and have several small salt lakes upon them.

At Paddington a deep lead begins in shallow ground near the Broad Arrow dam, and has been followed past Paddington to Smithfield, where the ground is about 100 feet deep. Here the old watercourse seems to widen and flatten, giving abundance of gravel with very little gold, and work could not be continued. The flats under which this lead runs are an extension of the Black Flag Lake basin.

Near Mt. Pleasant, between Broad Arrow and Black Flag, a lead started shallow on the high ground and soon became too deep under the flats to be readily followed. Borings have proved it to be 125 feet deep, and there seems much likelihood that it is a branch of a larger lead running southward under the Black Flag Lake, and more than 100 feet below its present bed.

At Siberia, a deep lead is found at a depth of 95 to 100 feet under what is now a hill. Some mining work done on this showed it to be a buried watercourse.

At Kurnalpi, the celebrated alluvial workings were on the slopes of a hill on the edge of a lake, and the ground became rapidly deeper approaching the lake.

At Nunngarra, on the Black Range, some work was done on two leads, one at least of which was traced to a depth of 40 feet. They disappear under flats through which they have not been followed.

At Lake Darlot, a quite similar lead was lately followed from shallow beginnings on the hills near the St. George mine down into ground about 70 feet deep, under the flats surrounding Lake Darlot, but has not been traced actually under the lake. Evidence that the ground deepens rapidly towards the lake is also seen in some of the workings in the flats at the west side of the field.

The above are all cases into which the writer has made personal examination, and to him there seems no doubt possible that the leads are old watercourses in which there was a certain amount of concentration of alluvial gold by ordinary river sorting action. The beds usually contain rounded and subrounded pebbles clearly due to attrition in running water. The most typical gravels are those in the Paddington and Oversight leads. There is generally much clay and sand with the gravel or immediately over it, and above the lowest part of the filling it is very usual to have thick beds of unctuous clay or "pug" of which the Kanowna "pug" is the most marked and well-known occurrence. In the Oversight lead a layer of hard dolomitic cemented material lies in places over the "wash" in the deep ground. Above the clayey and sandy layers nearly all the leads have a thick layer of oxide of iron, often showing concretionary and botryoidal structures, but not in my opinion properly to be regarded as true laterite. There is a general scarcity of included superficial matter, and much of the iron oxide is so pure as to suggest that its origin was as a precipitated iron oxide rather than an efflorescent laterite. The normal succession of iron oxide upon fine sedimentary cays in these buried valleys suggests slow filling under lacustrine and subsequently marshy conditions, in which first fine silts and afterwards iron oxide precipitates were accumulated. The capping of leads by masses of somewhat spongiform oxide of iron is so very characteristic in this State that the finding of a line of this sort of iron oxide, which is easily distinguished from laterites and gossans, may almost be regarded as a probable indication of deep ground, with possible gold, beneath it. In all the leads which have been examined by the writer, the deep leads appear to have been filled up and buried during a period long antecedent to the actions which have given the existing surface its present shape.

Opposite the Kanowna railway station on the head of the "town lead," we find a very hard silicious fine conglomerate lying over the wash layer in the lead. A somewhat similar hard cherty quartzite caps a small hill not far from the road to the racecourse, and under this cap there is loose quartz gravel made up of pebbles of the thoroughly rounded marine type. Where this occurrence fits into the geological history of the locality is at present a matter of speculation so far as the writer is concerned; it is however, evidence of lacustrine or marine conditions in that area in no very distant geological period. The little gravel hill is quite isolated, and is the only one of the sort seen by the writer anywhere in the district, and it is certainly much older than the last stage of surface sculpture. It may be perhaps connected with the "cement" (fine grained conglomerate) beds of Kintore, but is evidently a relic of an older superficial formation which has otherwise almost entirely disappeared.

The Deep leads, however, are not by any means the only proof that there is often an older land surface buried under the existing plains, and which is often at such variable depths below the latter as to show that it was not so uniformly level as the present plain surfaces. This is quite often seen in mining shafts and in stopes which come up close to surface, it being not at all uncommon to find much variation in the depths at which the bedrock is found beneath the surface. This deep "surface" or "made ground" as the miners commonly call it, often gives considerable trouble in tracing the outcrops of reefs into the flats, as it has to be sunk through to find the outcrops. Depths of "surface" up to 20 feet are not uncommon. Much greater depths of it are often found in sinking wells, many of which go down 30 to 100 or more feet before the bedrock is reached. Unfortunately it is hard to get exact data on this matter, as the well-sinkers rarely make any distinction between soft weathered portions of the bedrock and the detrital deposits which cover it. There are a great many cases known where wells of quite considerable depth are sunk almost from surface in soft weathered rock, which is merely the bedrock softened and kaolinised by weathering, and areas of such rock appear to be as useful in acting as reservoirs of under-surface water as deposits of superficial detritus. The records of ground passed through in well-sinking, therefore, are rarely at all dependable as showing whether the sinking is in detrital material or in weathered bedrock. A good deal of attention has been given by the writer when travelling about the fields to examining the dumps thrown out from the wells, and in making inquiries from men with knowledge of them to ascertain the depths at which the true bedrock has been encountered, and there are a large number of instances where the sinking has been in detrital material to considerable depths. Comparatively few, but still a few, cases have been noticed where water-worn gravels have been thrown out among the stuff sunk through. One very good instance is a well on the road from Rothsay to Field's Find, about half-way between the two so far as memory serves, where the dump of the well showed a good deal of well worn shingly gravel. This well is sunk in the plain surrounding Lake Monger and merging into the bed of the latter by the characteristic imperceptible gradations previously referred to.

From a good deal of scattered evidence of this sort, the writer has formed the conclusion that the surface of the bedrock below the existing plains is generally somewhat variable in its relief, and that if the covering of detrital material could be imagined as removed, it would appear as a surface of gently undulating hills and hollows, such as might be expected of the surface of a peneplain reduced to approximate base level by subaerial agencies, and traversed by numerous watercourses of slight grade and consequent small depth of erosion of their valleys. But these surfaces have since been submerged under the system of large lakes of which the existing salt lakes are only the shrunken remnants, and their inequalities of relief have been filled up with lacustrine or marine drifts and sediments, and so reduced to the extremely complete state of planation in which they are now found. While it is probably quite true that the main peneplanation of the bedrock as we now find it was due to sub-aerial erosion, it seems to me therefore that the final touches giving the landscape its existing peculiar characteristics, were given by submergence of the peneplain under considerable bodies of water.

MATERIAL OF PLAINS.

The materials composing the plains have always appeared to me very much more consistent with deposition as marine or lacustrine sediments than as wind-borne material. Nothing is more characteristic of the goldfields plains than the way in which they are covered over immense areas with a coating of stones at surface. Very many of these stones are oxide of iron pebbles often showing concretionary structure and which may well have been formed almost in situ as pisolitic growths. We know that many of our typical laterite cappings both on the granite hills of the Darling Range, and on the sedimentary drifts of the coastal formation, appear to be formed first as small pisolitic concretions in the surface soil which are added to in course of time as solutions carrying iron are drawn toward the surface by capillarity and the iron fixed by evaporation and further oxidation. In the same way it is quite possible that many of the iron oxide pebbles on the goldfields plains may have been formed very much where we now find them, and it may be pointed out that this explanation of their presence would apply whether the superficial covering was formed from either wind-borne or water deposited sediments. If the superficial soil is to be regarded as wind-borne this explanation of the ironstone pebbles is almost the only one possible, for it is clear that these heavy pebbles could not have been wind-borne to any appreciable extent. As a matter of personal opinion the writer does not attach much faith to this explanation of the formation of the iron oxide pebbles, as most of them seem to him not to be concretions *in situ*, but rather more or less worn concretionary laterite pebbles which have been moved from their place of origin and involved in sedimentary drift. They are often much mixed with pebbles of jasper, chert, and other hard and weather-resistant rocks, and fragments of white quartz. In places where the bedrock is close to the surface, it is not at all uncommon to see the surface so thickly strewn with quartz fragments as to be white in colour over quite extensive areas. Usually such quartz is not perceptibly water-worn, the fragments being sharp-angular or no more rounded than is usual with fragments of even hard rocks which have been exposed to weather on the surface of the ground, but every now and then it is by no means uncommon to find fairly well rounded pebbles of these hard rocks. It is not at all unusual to find that when trenches have been cut through areas where much fragmentary quartz is visible that the bedrock is not so close to surface as one might have thought, but is covered by several feet of superficial soil, all containing a good deal of the fragmentary quartz. It is difficult to understand how wind borne material could have through it heavy lumps of material mounting upwards from the bedrock, but the explanation is simple if we regard the drifts as sedimentary, as water has very considerable lateral transporting power. The stony layer is usually much more noticeable right at surface than on sinking a little way downwards, often appearing as if angular gravel had been thickly spread purposely over brown soil. This is doubtless due to superficial concentration of the heavier stones included in the soil. The advocates of the theory of the soil being wind-borne material, if they can succeed in explaining satisfactorily why heavy angular fragments of stone should be distributed through the superficial material, can easily explain the concentration of a superficial layer by appealing to the removal of the light soil by wind and rain, as no doubt these agencies are quite capable of so explaining the occurrence. At the present moment, we know that wind *does* blow away some dust from the surface, and that rains wash away soil as mud, leaving any heavier material in the soil accumulating as a layer of superficial gravel. The only difficulty is to see, if the stuff was wind and rain borne in the first place, how it came to be so full of stones which could be so concentrated on surface. The theory of aqueous deposition finds no difficulty in explaining the occurrence of the stones in the drift—quite similar muds with stones in them may be seen along the shores of Lake Cowan any day one cares to look along the trenches dug for the Norseman Causeway—but suggests as an explanation of the superficial layers of stones a certain amount of concentration of the heavier material by water removal of fine silt as well as by the subsequent accentuation of the same action by rain and wind after the lake waters have gone and the beaches have become dry land.

The "made ground"—to use the miners' term—quite often shows alternations of more sandy and more clayey material as would be expected from deposits in water, and in no case has the writer come across any considerable mass of such ground which he could regard as even probably derived from accumulations of wind-borne dust and sand. The physical character of the superficial soils overlying the bed rock seems to him to be quite against the theory of wind deposition.

SAND HILLS AND SAND PLAINS.

In this statement, however, sand-hills and superficial sand-drifts must be excepted, but these also when examined present notable features which are of much consequence in arriving at a theory of their formation. It may seem the "most unkindest cut of all" to the supporters of the wind-erosion theory to claim their sand hills in support of that of water planation, but it is in the position and behaviour of the sandy areas that the writer has found what appear to him to be powerful arguments in favour of the theory of lacustrine or marine planation as against that of wind-erosion. Sand-hills and sand-patches are found very commonly all over the country at all levels, but it is very noticeable that the biggest and best formed sand-hills, except those close to the coast, are usually, so far as the writer's own experience goes, on high land surrounding the lake plains. One of the most extensive sandy areas encountered on the goldfields, is crossed on the road from Gabanintha to Wiluna, a short distance east of the rabbit-proof fence. Here the ridge between the Lake Annean to Lake Austin lake plain and that surrounding Lake Way and Lake Violet rises to a considerable height above these plains, and the sand is very heavy to traverse. It is formed often into well-marked sand dunes of typical shapes, now covered with spinifex and small scrub, and rarely shows signs of having been in motion as drifting dunes for a very long time. The dunes are practically fixed by the vegetation, and wind appears to have but little effect on them. The sand-ridges are found southward to Birrigrin and Barrambie, being very difficult to traverse between these two centres, and the rabbit-proof fence from Barrambie to Gum Creek passes through them for many miles. Everywhere they are on the high ridge on the edges of the lake plains, and are practically fixed in position by a coating of vegetation.

The Barr Smith Range, passed over on the old road between Kathleen Valley and Cork-tree well, on the way to Wiluna, is another very characteristic sand-plain, with only very small dunes, now well fixed by vegetation. It is high ground on a ridge between two extensive brown-soil plains. This tract of sandy country is found westwards nearly to Birrigrin and Black Range. Another similar stretch of sand hills, very bad for travelling through, separates the plains near the Mt. Sir Samuel mining area from those of New England and Lake Darlot, there being a high sandy ridge between them from the New England country nearly all the way south to Wilson's Patch. The sand hills are particularly well seen where the road from Mt. Sir Samuel to New England crosses the high ground, but here, too, the dunes have every appearance of having been long fixed in their existing positions, being well covered with scrub.

Another well-known line of sandy country lies between Menzies and Davyhurst, on the north and south ridge between the Goongarrie Lake plain and that of Siberia Lake. Here too, the dunes seem to have been long fixed by vegetation.

Between the Jaurdie Hills and Coolgardie there is a sand-patch several miles in width on the highest ground between brown soil flats on either side of it, and several similar patches are seen along the railway line between Northam and Kalgoorlie. Near Tammin it is very noticeable that the sand-patches are usually, if not always, on the ridges between the fertile lower-lying plains.

Going down the rabbit-proof fence from Burracoppin to Ravensthorpe, a great deal of very sandy country is traversed, but even there the prevalence of the sand on the higher ground is very marked.

Another extensive sand-plain is crossed on the road from Yalgoo to Rothsay, on the high ground between the Yalgoo plain and that of Lake Monger. Here no dunes were seen however, the sand plains being remarkably flat.

Yet another good example of sand plains on high ground is seen in travelling from Northampton to the old Geraldine mines on the Murchison River. The road rises up off the fertile plains and undulating country to the north of Northampton on to a sand-plain on a high ridge separating the valley of the Bowes River from that of the Murchison. This plain shows few and only very small dunes where seen by the writer, and forms a distinct sandy plateau considerably higher than the brown-soil country on either side of it.

Now how are we to account for this extraordinary predilection of the sand deposits for the higher ground? It is not the experience of wind-action elsewhere, where its effects on sand can be watched in progress, as in the case of the coastal dunes, that the plains should be swept free of sand and this accumulated on the highest ground round them. It is true that there are very frequently sandy areas in the plains, so that they are not clear of sand by any means, but the freedom of great areas of them from sand is very remarkable if their erosion has been due in any marked degree to the cutting action of wind-driven sand. Where we see drifting sand dunes, as on the south coast, it does not seem to matter much whether the ground is high or low; the dunes march forward before the prevailing winds over high and low ground without discrimination. There is no visible tendency to build up on one spot more than another, except right along the beaches, where the loose sand thrown up from the sea is first stopped by the defence of vegetation. Sand-hills build up most characteristically along this frontier, between the fresh supplies of sand ever thrown on the beach by the waves and the barrier opposed to its inward drift by the fixing action of vegetation. Among the inland lakes excellent examples of sandhills round the margins of the lakes are quite commonly seen, for example on the south side of the Siberia lake on the road from Davyhurst to Siberia, and on the shores of Lake Koorkoordine on the road from Southern Cross to Koolyanobbin. And just as we often find marginal sand dunes round the existing salt lakes, so the main belts of sandy country correspond with the position in which we might expect sand dunes to have been formed round the older and larger lake-beds, which now form the brown soil plains. They are still in position where they were formed when the lakes were filled with water, and are therefore on the high country separating the lake basins.

While on this subject it is instructive to notice the very different type of surface prevailing in the sand dune country from that on the brown-soil plains. Where the surface has been moved obviously by wind it is uneven, and in small hills and hollows resembling waves, which in cases rise to the magnitude of dunes where the bodies of sand are larger. We at once get the typical wind-shaped surface, exemplifying the well-known fact that material accumulated by wind lies in waves and drifts and not in level deposits. But how then can we ascribe the levelness of the plains to wind action? Wind is not a cutter of level surfaces, but of uneven ones.

It is readily admitted that windstorms of much violence are not uncommon on our fields, and on any fine day in summer it is quite usual to be able to see several whirlwind clouds of dust dancing over the landscape at one time. But so far as the writer's observation has gone, it is very uncommon, if not unknown, to see any signs of the ground being worn away perceptibly by dust storms. If they were a strongly-operating cause of removal of the surface soil we should expect to see quite commonly, trees with the top portions of their roots laid bare by the wind, and standing well out of the soil, but the general appearance of the trees is usually quite distinctly the contrary of this, the soil often appearing rather to have accumulated round the stems than to have uncovered the roots. A good deal of attention has been given to observing this point, and the writer is quite satisfied that the vegetation on the plains usually shows no sign of any appreciable wearing down of the surface soil by wind erosion.

TRAVERTINE DEPOSITS.

Turning to another feature of many of the lake plains, it does not appear to have attracted much notice hitherto that deposits of impure limestone are not uncommon in many of them. Usually it has the appearance of travertine, and where it has been described it seems often to have been somewhat hastily assumed to be formed by emanations of lime-bearing solutions from weathering of underlying basic rocks. This may quite well be true in some cases, and the association of the closely allied magnesite deposits with basic rocks seems fairly well established in some of the occurrences of this mineral in this State, though there seem to be others in which no such association has yet been made out. Some of the largest travertine deposits seen by the writer, however, do not appear to be on basic rocks at all, so far as can be seen. On the south side of Lake Annean on the road to Cue, there is a large amount of this travertine, apparently on granite bedrock, and another extengive occurrence is seen near Nallan, at a favourite picnic ground to the north of Cue, where the railway authorities have established a ballast pit from which the travertine is extracted for ballasting the railway. Another large patch of similar limestone is passed over to the south-east of Quinn's, on the road to Erroll's, in an area where the visible bedrock is mostly granite. Other occurrences are near Lake Miranda and Lake Way, a short distance out from the margin of the present salt-pans. Several other little patches of similar limestone have been found useful on the goldfields for burning for lime for cyaniding and building operations, although the mineral is usually too impure to give good quicklime. A short distance out from Southern Cross on the road to Marvel Loch, there is a large amount of concretionary limestone, in spherical nodules from the size of peas up to that of cricket-balls, which was burned for lime in the earlier days of the Southern Cross Goldfield. These are on a dioritic bedrock, but where the deposit occurs this rock crops out at surface in what appears to the eye to be a remarkably unweathered condition giving little support to the explanation that the carbonate of lime is derived from it. The position of the lime deposit is only a few feet above the plain of Lake Polaris, and on the margin of it. The travertine deposits at the south end of the Causeway at Norseman are quite similar to most of those just mentioned—except for the spheroidal concretionary one at Southern Cross, which appears to be different from the rest—and are found in patches for some distance up on the Norseman hill, and at first there was no reason to think that they were anything else then superficial travertines derived from the greenstone bedrock. But the discovery by Mr. W. D. Campbell, of several species of marine fossils in these limestones, here much opalised, has thrown quite a new light upon them. In this case there can be no doubt that the calcareous travertine represents the much weathered condition of a former bed of shells and shelly detritus, and bearing this in mind together with the marginal position on lakes of most of the other travertine areas, it is not a great assumption to make to suppose that they also were shell banks. Very little attention appears to have been given by any observer to the calcareous deposits, probably owing to exigences of travel and acceptance of the prevalent idea that they were merely travertines from basic rocks, but it seems to the writer that there is a very strong case made out for thinking that they are most probably of marine origin, and that they also will be found to be fossiliferous when well searched. They will probably prove to yield the decisive evidence as to the truth or otherwise of the theory of a recent marine invasion of our goldfields areas.

The spongy to pulverulent, yet often also concretionary and nodular character of these travertines, and the frequent occurrence with them of opalised matter, may easily be the result of subarid weathering of banks of shell sand. The thin coating of superficial limestone along the shore at Port Hedland is of very similar character, and to a passing glance shows little or no sign of being formed from organic detritus, yet with marine life swarming between tide-levels on the shore close by, it can hardly be doubted that the limestones are derived from similar organic remains. Much of the bedded limestone near Hopetoun, similarly, which is often pretty distinctly stratified, has also a similar travertine-like character. In the railway cuttings between Cottesloe Beach and North Fremantle we see excellent sections showing a great amount of re-arrangement of the calcareous material by solution and reprecipitation along lines on which passage of water through the mass has been possible, and there seems no good chemical reason to doubt that the transformation of shell sands into travertine-like deposits could easily result from superficial weathering under the conditions of small precipitation and rapid evaporation prevalent on our fields. The fall of rain upon the porous material, and the subsequent withdrawal of the water from the soil by capillary attraction to surface and evaporation, supply quite the ideal conditions for rapid and extreme alteration of superficial calcareous beds. It is suggested that this rapid weathering of calcareous matter may be a very sufficient reason for the absence from the lake basins of any of the signs of marine life which would be expected on the theory of their having been submerged under the sea.

SALINITY OF WATERS.

The next question to which study of the lake areas leads us is that of the degree and nature of the salinity of the natural waters found in the goldfields. This is a matter on which much light is likely to be thrown by the greatly hoped for publication at an early date by the Geological Survey of W.A. of all the numerous analyses of the waters of the States, which have been made for various purposes. From examination of a large number of these analyses the present writer is strongly of opinion that they point to derivation of their saline contents from a marine source rather than directly from integral constituents of the bedrock. It is obvious that strata laid down as sediments under sea water must contain a proportion of sea-salts in them when they are again elevated to become dry land, and even the old crystalline rocks, when their upper surfaces have been under the sea may well be assumed to have a large amount of salt water forced into them through all possible joints and fissures in them, which would mostly be retained when they were again elevated above sea level. Such interstitial salt would then have to be regarded as of marine origin, and quite foreign to the solid constituents of the rocks in which it is entangled, and would be capable of being washed out of them. It would thus be different in origin from salts set free by the weathering and chemical changes affecting the original materials of the rock itself. The commonly accepted theory that Western Australia presents a very old land-surface which has never been submerged for ages, however, demands that the saline accumulations must be regarded as principally derived from the integral minerals composing the bedrock. But so far as analyses have gone, there is very little chlorine in the crystalline rocks, and it is very difficult to believe that the enormous quantities of salt present in the salt pans and the surface soil and shallow underground waters of this State can have been formed merely by prolonged concentration of the minute amounts of chlorides as yet demonstrated to be existent as a primal constituent of the crystalline rocks. It is often stated that the areas occupied by the greenstones yield ground water much more highly saline than that of the granite districts, and also that the soda-granite country is salter than that composed of orthoclase or microcline granite. The writer is very dubious as to these statements being acceptable as correct generalisations, as there are several granite regions towards the south coast where the ground waters are extremely salt, and other greenstone districts, especially in the Murchison, East Murchison, and Mt. Margaret fields, where fresh water is found just as commonly as in the granite. In the absence of analytical proof that the greenstones average considerably higher than the granites in percentage of chlorine in their crystalline constituents, the writer is inclined to ascribe any local differences in salinity which may be noticed rather to the much more jointed and often schistose structure of the greenstones as compared with the granites, and their consequent greater liability to inclose interstitial salt water whose salt is not necessarily derived from the enclosing rock. A somewhat curious instance is seen at the Govrnment dam at Cordingup Creek at Ravensthorpe, where some 25,000,000 gallons of fresh water are impounded from rains falling on a granite catchment. Near the back of the dam one of the diorite dykes very common in this district crosses the Cordingup Creek, and at this point it was found that there was an exudation of salt water in small quantities, but sufficient gradually to affect the fresh water, and to require special measures to be taken to cut off the salt water feeder. It is incredible that this salt should be leached out of either the solid crystalline granite or the equally dense crystalline diorite, both of which are practically unweathered at this point, but there is nothing strange in there being salt water in the fissures along the margins of the dyke. Except for a short time during rains almost all the natural waters of the Ravensthorpe district are very salt, whether the bedrock is granite or diorite, and salt water must therefore be expected to accumulate in all joints, breaks, and other fissures of the rock.

By tracing the conditions of salinity of the country from the south coast northwards, the writer thinks that we shall be able to see an explanation of most of the phenomena exhibited, and to conclude that they are in keeping with the theory of marine submergence, though inexplicable on that of sub-aerial peneplanation. All along the south coast from Albany eastward to Esperance, the country is very salt, most of the streams—even running ones—being quite undrinkable even by cattle during the drier parts of the year. When flooded by rains they may be fairly fresh for a little while, but they soon become salt again, and even in rains the spectacle may be witnessed of a rushing turbid torrent of salt water. The Palinup River, Salt River, Jacup River, Hamersley River, and Phillips River may generally be seen running a little, where crossed in travelling from Albany to Ravensthorpe, but are very salt. On the granite rocks near the head of the Hamersley River, there is a camping place where a little fresh water may generally be obtained, but where the writer found that nearly all the water trickling over bare granite was quite salt. Yet it is not the granite which is yielding the salt, for rock holes in the granite are found in which the water remains perfectly fresh for weeks. The celebrated "Night Well" on the Salt River was in granite in the valley of the river and only a few feet above its bed, and above it and below it in the bed of the river there were salt water pools when the writer visited it in 1902. The fresh water was in a crevice in the granite and so had every opportunity to dissolve salt from it if the granite were the source of the salt, but the water was quite fresh. So also tanks blasted out of the granite, and with a bare granite catchment, in other parts of the southern district, retain their water perfectly fresh. The hard granite evidently is not the source of the salt, but all the overlying soil and the sand plains appear to be full of salt. It is clear that every time the streams run they must carry away a large amount of salt to the sea, and it is an indication of the enormous amount of salt available, and also of the comparatively short time during which the leaching action can have been going on, that there is still so much yet to be removed.

Going further north, the country still remains salt, irrespective of whether granite or greenstone is the bedrock, but there is no difficulty in getting fresh water during rains for storage in dams. The surface layers of the ground have been washed fairly free from salt by the rains, and in favourable places fresh water "soaks" may be found, especially where fresh water pouring off bare granite rocks has accumulated under superficial drift round their bases. It has been able in course of time to wash out and press back the salt water. Wells in such places however, are very often found to turn salt very rapidly when used, the drainage into the well evidently soon drawing back the salt water which had been displaced by fresh. It is also very often found that one must be very careful about deepening such wells, as the fresh water zone is often quickly passed through and salt water found below it. A curious instance of fresh water in salt country was found when boring for water at the Jaurdie Hills not far from Coolgardie. A small valley comes out of the hills, down which at times of heavy rain there is a fairly strong flow of water which soon is absorbed when it reaches the plain. Borings found that the alluvial drift in the flat at the mouth of this little valley was some 60-70 feet deep, if my memory is correct, and three of these bores got salt water. A fourth, put down within the triangle formed by the first three, obtained fairly fresh water, but when a well was sunk the water soon became salt. The explanation doubtless is that the alluvial drift was salt in the main, but that the fresh water from the hills had established a line of flow for itself through the drift, along which the salt had been washed out. The fresh water bore happened to hit this channel and got fresh water, but the demands of a well soon brought in the salt water from the surrounding salt country. Another fresh water well at Coolgardie in its early days was a bonanza for a short time to its owner, but it soon also became salt.

Continuing northwards, fresh water wells and soaks become much more frequent and more permanent, and the salinity of other wells is generally much less than in the southern districts. North of Kookynie, fresh water wells become quite common, though the lowest lying ground is apt to be very salt, and salt lakes are still common. Rising into still higher country the wells are on the whole fairly fresh, and many of them excellent water, though there is often great variation in the salinity of wells quite near one another. Is it not pretty clear that height above sea level is the principal factor in the problem, and that the country which stands highest has had the best chance of having the salt removed from it by rains and the gradual down grade flow of the ground waters? Also if the theory of submergence under the sea by subsidence and subsequent emergence by elevation be correct, the higher country has been longer exposed to the washing action of the rains, and has been more thoroughly leached of salt than the parts which were later in emerging. The sub-aerial theory might explain the accumulation of the salt in the lowest parts of the plains where the water gathers, but it does not explain why the South Coast region which has twice or thrice as great a rainfall as the country further north should be the saltest portion of the State.

The salt waters found in our salt areas vary greatly in total percentage of saline constituents per unit of water, and also a good deal in the relative amount of the various salts present, but it is very notable that the salts present are principally those also found in sea water, and are such as might result from the leaching of sea salt from superficial sediments. In this process certain reactions are liable to take place between the salts and the constituents of the soil which may have the effect of rendering some portions of the former insoluble, with interchange of other soluble salts not originally in the sea water in place of them. The calcium sulphate in sea water, for example, might readily react with sodium carbonate formed by the weathering of sodium-bearing silicates in the soil, to form the much less soluble carbonate of lime and sodium sulphate. Many such reactions must be expected which might soon alter the quantitative proportion between the various salts from that normal in sea water. Taken on the whole, the salts in our salt lakes and wells may truly be said to be of a marine facies, sodium chloride being always predominant, and constantly associated with much of sulphates of lime and chlorides and sulphates of magnesia. In some cases the magnesia salts are more plentiful than usual, and the composition of the saline constituents of the water then approaches that of the "bitterns" formed when part of the sodium chloride of sea water has been crystallised out of it. Whether such removal of sodium chloride be the reason of the relative excess of magnesium salts or not, it may be noted that very similar variations in the proportions of sodium and magnesium salts are common in brines pumped from saline strata in salt producing districts. In these, too, a like differential removal of certain of the salts must have taken place as the marine origin of these salt beds is undisputed. and the proportions of the salts present must therefore have been originally those normal in sea water.

The insufficiency of the theory that the salt in the ocean is derived from mere evaporative concentration of the salts brought down by rivers has frequently been remarked upon. Julius Roth, for example, found that the proportions of the salts of river and sea water were:—

	Carbonates.	Sulphates.	Chlorides.
	%	%	%
River water	80	13	7
Sea water	0.2	10	89

The learned authors of the article on "Ocean and Oceanography" in the Encyclopedia Britannica, who quote Roth's figures, also remark: "The salts of salt lakes which have been formed in the areas of internal drainage in the hearts of the continents by the evaporation of river water are entirely different in composition from those of the sea, as the existence of the numerous natron and bitter lakes shows." The water of Lake Van, for example, contains 5.3976 grams of sodium carbonate per 1000 grams of water, to 8.0500 grams of sodium chloride. The principal soluble salts formed by the chemical action of the weather on the compound silicates which form the bulk of the crystalline rocks are carbonates or bicarbonates of the alkalies and alkaline earths, and as a natural consequence these salts must be expected to predominate in the surface waters leaching through masses of weathering rock. Unless chlorine be present as a constituent of the rocks, no considerable amount of sodium chloride can be formed from such weathering, and unless, therefore, our crystalline rocks can be shown to carry a quite perceptible amount of chlorine in them on the average, there is no reason to look to them as the source of the salt so plentiful in the ground water. So far as chemical analyses have been published chlorine has very rarely been noted as a constituent of our crystalline rocks at all, and the petrological descriptions do not indicate any unusual abundance of chlorine-bearing minerals.

In this connection it may be of interest to refer to the tables of analyses of natural waters in Australia given in the Report of Proceedings of the Interstate Conference on Artesian Waters, 1912. Appendix B. gives 54 analyses of bore waters in New South Wales, characterised by the carbonates of sodium, potassium, calcium, and magnesium being in almost all cases greatly in excess of the sodium chloride present. In Appendix H. there are several hundred analyses of New South Wales artesian and subartesian waters, and the great majority of these also show alkaline carbonates in large excess over sodium chloride, although a few are mainly saline waters. In Appendix M., Tables 11 and 111 give 65 analyses of waters from Western Australia, but in these sodium chloride is almost always in large excess over all other salts present, and carbonates are of quite subordinate importance. The reversal of the relative proportions of chlorides and carbonates in the ground water at once suggests some essential difference between the conditions of the two provinces of New South Wales and Western Australia. Appendix T. shows 48 analyses of bore and well waters from the Mallee country of Victoria, with a great preponderance of sodium chloride over all other constituents. In Appendix Y. there are 34 analyses from South Australia, of waters from the Great Australian Basin; in 28 of these sodium chloride is the most abundant salt present, but in 6 cases sodium carbonate predominates, and in 11 the sodium carbonate is next to sodium chloride in abundance. In the table of analyses of Queensland waters, the relative proportions of the various salts have not always been determined, but it may be seen that in a large number of cases the sodium carbonate is the salt most plentifully present, while in others sodium chloride predominates. It seems rather probable that a careful correlation of all these different analyses according to locality and composition taken in conjunction with the geological structure at each bore might give useful results in assisting to arrive at some conclusion why certain regions have developed alkaline rather than saline ground waters. For the purposes of the present paper the main point to be emphasised in these analyses is the great salinity of the Western Australian ground waters as compared with those of Eastern Australia. It is submitted that the most feasible explanation of the occurrence of such abnormal quantities of common salt is that it is derived from sea water within a space of time so recent, geologically speaking, that it has been insufficient to allow of the salt being either carried back to the sea or concentrated entirely in the low-lying salt lakes. All the rain that falls on the surface tends to carry the salt into one or other of these final receptacles, and the fact that this action has not yet succeeded in removing the salt from the soil to anything approaching the extent that must follow from long continued leaching by rain, may be taken as supporting the view that the present condition is of comparatively recent occurrence. This argument, however, is weakened by the fact that the capacity for evaporation of water in this State very greatly exceeds the precipitation, so that it is possible and in many cases probable that very little if any of the rain falling on a district goes to increase the body of ground water and to help to drive it forward on its slow but constant course seaward. A great deal of it simply sinks into the earth for a time, but is brought up again by capillarity and vegetation and evaporated. It is therefore quite possible that the salinity of the soil of such a district might remain practically constant for an indefinite period. The most that can be regarded as certain is that the salt would tend to become more and more collected in the lowest lying portions of each district, and that in course of time the slow seaward movement of the ground water must tend to restoration of the salt to the ocean. That this result has been attained in the higher central regions of the State more thoroughly than in the southern coastal ones has been already pointed out.

The dogma that the central portion of this State has been a land-surface from time immemorial, which has been re-iterated so often as to have become generally accepted belief, seems to the present writer to be founded on no sure basis of facts and to be entirely opposed to the physiographical evidence above narrated, which all goes to show that the very shape of the landscape as we now see it has been mainly impressed upon it by the action of bodies of salt water. It is difficult to discover why such a theory should be held, for there is a good deal of evidence that the sea has extended over the greater part of the State not only once, but repeatedly since the very ancient rocks forming our goldfields were first exposed as a land surface. These oldest rocks, taking all the Pre-Cambrian ones together, are uncovered at surface at the present day in the Central and Eastern Goldfields, but in the greater part of the northern half of the State they are overlain by the much younger Nullagine formation, and there appears to be at least a strong possibility that this reappears in the Stirling and Eyre Ranges in the South. There is quite a considerable degree of probability that the whole of the State has been covered by the Nullagine formation, lying upon a previously planed-down surface of the Pre-Cambrian rocks. Subsequent erosions have removed the Nullagine rocks over huge areas. After the formation, upheaval, and land-erosion of the Nullagine beds there has again been depression of large parts of the area of the State below sea level when the Carboniferous formation was laid down, which must have extended over a very large portion of the State, as we still find large areas of it in districts so far apart as the Kimberley, Gascoyne, and Collie mineral fields. The elevation to which these beds extend suggests that when they were laid down there was much probability that a great deal of the rest of the State was also submerged. Then still later there must have been submergence of large portions of the State when the Mesozoic rocks were laid down which we find from Gin Gin northwards to beyond Geraldton, up to considerable elevations, and the limestones of the Eucla plateau, found up to heights of about 1000 feet above sea level, point to a probably rather later period of subsidence and marine sedimentation over an immense tract of country. When the sea came inland to the northern edge of the Eucla limestone area it may well have flooded a great part of the Eastern goldfields which are now below the 1000 feet level, and a comparatively slight further subsidence would have carried it over practically the whole of the Central and Eastern Goldfields if the relative levels of the various districts remained the same then as at present. The Government Geologist has also described limestones, probably of Tertiary age, occurring at a high level near the head of the Oakover River in the Pilbara Goldfield, which would indicate a subsidence in Tertiary times sufficient to bring the sea a long way inland at that point.

It is seen therefore, that there is positive evidence of successive invasions of the sea well into what is now the interior of Western Australia, up to the Cretaceous and probably the Eocene, or even later periods, and there is no reason to suppose that the limits as we now find them of the formations then laid down were the extreme limits to which the sea waters extended. It is much more likely on the contrary that the sea extended over a great deal more country, in which no traces of its presence have been preserved.

Subsequent to the laying down of the Cretaceo-Tertiary limestones there have been further oscillations upward and downward of the land forming this State, with formation of the Tertiary to recent coastal limestones and sandstones. There is much doubt as to the thickness of these sediments, as some of the bores into them which appear to have gone to depths of 1000 to 3000 feet without getting through them are regarded by the Geological Survey as being in Mesozoic strata in their lower portions. The elevation to which they reach is also not at all certainly ascertained. On the Ravensthorpe Range near Kundip, there are patches of probably rather recent conglomerate at quite 800 feet above sea level, and if some of the recent sedimentary deposits at Collie, overlying the coal measures, near Kirupp, and at Greenbushes are taken to belong to the coastal formation (Tertiary to recent) they would indicate marine or lagoon deposition at a horizon now elevated 700 to 900 feet above the sea level. Here again it is improbable that the few relics still surviving of these beds would indicate the extreme height up to which the waters of the sea may have invaded the country, and it might quite well be that the subsidence of the land was great enough to flood the plains of the goldfields. It is submitted that as there is proof up to an elevation of 900 feet of subsidences sufficient to cause formation of probably marine sedimentary deposits there is no great assumption involved in supposing that they went on to a still greater extent so as to be sufficient to cause the sea to invade the interior at levels considerably above that elevation, and enough to impress upon the surface those features of marine planation which we now find to be characteristic of the goldfields landscapes. The subsequent elevation of the land would then lead to the formation of numerous salt lakes in the depressions of the generally flat surface, whether such depressions were due merely to inequalities in the level of the sea bottom or to slight deformation basins forming in the bedrock itself in the course of its elevatory movement. Some such unequal movements of portions of the upheaved block would be only what might be expected during a continental movement of elevation. Signs of such uneven motion are not wanting. A small fault, for example, has been found in the Siberia deep lead, throwing down the old gutter some six or eight feet, and at Coolgardie there is a very interesting patch of deep ground, about 400 feet deep, of probably Tertiary or Post-Tertiary age, which seems inexplicable unless it is a small sunken field or "grave" where a wedge-shaped piece of ground has been faulted downwards. It is not unlikely that such faults in the superficial sedimentary deposits are quite common, and they may be the explanation of the apparent sudden cutting off at times of the "deep leads." If there has been much faulting of this sort, however, there has been time since it occurred for all resulting inequalities of the surface to be planed smooth, leaving no trace of the faults at surface. The sunken field at Coolgardie for instance looks just the same at surface as any of the shallow flats in its vicinity.

It seems probable that the movements of elevation and subsidence of this country have been mainly epeirogenic rather than orogenic ever since Palaeozoic times. The Nullagine series of beds are usually characterised by gentle undulatory bending without severe folding; the Carboniferous beds mostly lie at low angles of dip without much appearance of bending, and the strata of Mesozoic and Tertiary age seem usually only very slightly tilted from their original bedding. Since the time when the Nullagine beds were subjected to a certain amount of orogenic crumpling there appears to be very little if any evidence that any of the subsequently formed strata have been compressed into undulatory folds to any appreciable extent. At Collie the tilting of the beds of the coal measures seems principally due to faulting rather than crumpling. In epeirogenic movements of elevation, faulting in parts of the moving landmass must be expected as a natural consequence of the readjustments of position of material incidental to the movement. An elevation or subsidence of an area of land of continental dimensions like the Western Australian Plateau would also require us to assume the existence of powerful faults forming the boundaries of the moving block, and it may be noted that the probable existence of some such faults has already been deduced from entirely different considerations, along both the southern and western coasts of this State. There is too little evidence to enable one to say yet whether there is any indication of the last elevatory movement being merely an even vertical one or whether one or other side of the block has been upheaved more than the others. It seems possible that the physiographical evidence may yet be so systematised as to lead to some positive conclusions being drawn on this point. A little tilting of one side or another of the moving block of ground obviously might have very important effects in modifying or even reversing the directions of slope of various parts of the surface, and so altering the flow of surface waters.

The most positive indications of marine conditions in the interior of our State are those already mentioned as having been found in the Norseman district near Lake Cowan. Here there are two occurrences of remains of undoubtedly marine organisms, one a thick bed composed almost entirely of sponge spicules, described by Dr. Hinde, in the Princes Royal Deep Lead, and the other a bed of marine shells in limestone, found by Mr. Campbell near the Norseman Causeway. The shellbed is described as being 35 feet above the level of Lake Cowan, and containing opalised casts of several species of late Tertiary or recent marine shells belonging to the genera, *Turritella, Pecten, Cardium,* and *Magellania.* The sponge spicules occur as a deposit in the upper part of the alluvial material filling the Princess Royal "Deep Lead," forming a bed said to be over 35 feet in thickness. Dr. Hinde's conclusion after examining the spicules was that the deposit was formed in the open ocean at some distance from a coast-line and probably in considerable depth of water, and he thinks them likely to be post-cretaceous in point of age.

The "deep leads" all over the State are old valleys which have been filled up before the present lakes were formed, and the Princess Royal sponge spicule deposits would go to indicate that they became filled up during a subsidence which brought the sea so far inland that the present site of Norseman was in deep water well out from the coast. This might perhaps have been during the time of the Cretaceo-Tertiary subsidence, which resulted in the laying down of the Eucla limestones, and if this date could be established for the case of the Princess Royal Deep Lead, it would probably apply generally to all the other deep leads of the State which are quite similarly buried under lake flats. It would not necessarily follow, however, that marine sediments should be expected to be found in all of these, as the first effect of a movement of subsidence would be to start the filling up with drift of all the valleys near the coast long before they became submerged under sea waters. The material found filling them as a matter of fact appears generally to be of sub-aerial origin and not marine. The Princess Royal valley appears to have remained open however, and to have become deeply submerged, giving the opportunity for collection in it of the deep-sea deposit of sponge remains. The more littoral shell-beds might have been formed at almost any period during this movement of submergence and subsequent emergence of the land, but probably at either an earlier or later stage than the spicule beds, and if the species prove to be altogether more recent than the Eucla limestone period, as appears to be the opinion formed at present, it would be probable that they belong to a Post-Tertiary repetition of the process of submergence and subsequent elevation much later than the Cretaceo-Tertiary one in which the Eucla limestones were formed. From their position they look like littoral deposits of an arm of the sea, occupying the site of Lake Cowan to, a depth at least 35 feet above its present level, and seem most likely to belong to the last period of the connection of the lake with the sea before the continuance of the elevatory movement cut the former off from the latter, and raised it up some 900 feet. The presumption would then be that the deep leads generally are mostly likely of an age between the times of the Cretaceo-Tertiary subsidence and elevation which gave us the Eucla limestones and a subsequent similar Post-Tertiary down and up movement which gave the more recent Norseman beds. The leads would represent stream channels in the land surface existing between the two periods of subsidence.

The marine deposits at Lake Cowan show positively that elevation from probably a considerable depth below sea level up to about 900* feet above it, has taken place at that point, and if Lake Cowan be admitted to be the residuum of a cut off arm of the sea, it is only reasonable to extend the same explanation to Lake Lefroy, Hannan's Lake, Lake Yindarlgooda, and Lake Lepage, which are connected with one another by plains into which the margins of the lakes merge imperceptibly. Hannan's Lake however, is at about the 1060 feet level. The plain country is traceable on to the north almost continuously, though studded with frequent island-like groups of hills, to connect with Lakes Ballard, Barlee, Raeside, Carey, etc., right up to Lake Way, the elevation of which is about 2030 feet according to Professor Gregory. The physiographical features of the country round Lake Cowan are quite similar to those of the whole lake tract right up to Lake Way, and if physiographical evidence is of any value, the shaping of the land surface has been due to like agencies all the way. At Lake Cowan we have direct evidence that the lake was once an arm of the sea, and the conclusion seems irresistible that the marine invasion extended inland along the lake country to beyond Lake Way. Such an extension would bring it over all the Central and Eastern Goldfields, unless the relative levels of the different parts of the country have been altered unequally, of which no evidence has been brought forward as yet, though there is no inherent improbability that such may have been the case, and indeed there is a good deal of probability that it would be so.

According to this theory the present shape of the land surface of the goldfields up to at least the 2000 feet level would mainly be that impressed upon it during the re-emergence of the land and retreat of the sea, probably in Post-Tertiary times, and in the writer's opinion the whole of the characteristic features now visible agree consistently with those which would be necessary consequences of such a history.

It will be interesting to find how this theory will stand the test of the biological line of argument, for if it be correct there would undoubtedly be consequences affecting the distribution of both plant and animal life. The theory would require that in Post-Tertiary times this State has been at times more or less of an Archipelago in a shallow sea, which would result almost inevitably in some amount of differential variation of both the fauna and flora cut off on the islands. The result to be expected would be that we should have somewhat marked faunal and floral provinces, difficult to account for if the land surface had been continuous for a very long space of time. This interesting subject is beyond the scope of the present paper, and is left to be dealt with by writers more conversant than the present author with the botany and zoology of the State.

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*Norseman Railway Station, 927 feet above the sea level.